USE OF CHART READERS FOR ANALOG TO DIGITAL CONVERSION OF HYDROLOGIC DATA

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USE OF CHART READERS FOR ANALOG TO DIGITAL CONVERSION OF HYDROLOGIC DATA

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At present, most hydrologic data from recording instrument charts are converted from analog to digital form by visual chart reading and manual tabulation. Transparent overlays are used to speed this operation, but it is still a slow, tedious process. The conversion becomes especially difficult when there are rapid fluctuations in the chart trace, such as those caused by flashy runoff. Furthermore, after the raw data have been tabulated, they must then be entered manually into a card punch or tape machine if digital computers are to be utilized in reduction and analysis of the data.

Machine chart readers can be used to convert data from hydrologic charts to suitable digital form for computer processing in one step. The hydrologic charts are placed on the viewing screen and the trace or traces are reduced to digital form by manually selecting and automatically printing out in computer language the locations of sufficient points along the trace or traces. Other pertinent information (date, station, and time) is added to output for each event, and a series of cards or a tape is produced that represents all information shown on the recorder chart. The speed with which data from recording instrument charts can be reduced to digital form by machine chart readers depends upon the type of chart to be processed, the fluctuation of the trace or traces on the chart, and the adaptability of the machine to the specific chart.

Several corporations manufacture chart readers that can be used for the conversion of hydrologic data from analog to digital form. These chart readers vary in design and cost, but can be roughly divided into two groups. The first group consists of the less expensive and simpler type referred to by the manufacturer as semiautomatic; the second group consists of the more expensive and versatile so-called automatic systems. Both types of chart readers, when attached to a standard card punch or an electric typewriter, or both, will convert traces on hydrologic charts to digital form. The relative efficiency of the two systems varies with the types of hydrologic record to be converted. In the ensuing discussion of the two types, they are referred to in the terms of the trade as semiautomatic and automatic, though these terms are not truly definitive.

SEMIAUTOMATIC CHART READERS

The semiautomatic chart reader has a single freely variable axis. That is, only movement along one axis will be automatically tabulated when the readout button is pressed. The Y-axis (gage height, depth of precipitation) is normally chosen as the variable axis with the intervals of movement along the X-axis (time) being predetermined by the operator. If the time intervals

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vary continuously and unevenly, the operator is under considerable pressure, and errors are more likely to occur. If the time intervals remain constant for long periods, e.g., noon and midnight readings from runoff records of base flow, operation of the semiautomatic system is quite efficient.

One model of a semiautomatic chart reader is shown in figure 1 and a model of the automatic chart reader is shown in figure 2.[2] A closeup of the screen, movable bridge, and overlay of an automatic system is shown in figure 3. This part of the equipment is similar in both semiautomatic and automatic systems. Points along the trace are tabulated by positioning the curved reference line (vertical for rectilinear charts) and overlay line, to intersect on the chart trace. The three lines must intersect at one point to record the correct coordinates of the point.

Technical information on the basic operation and maintenance of semiautomatic chart readers is available from the manufacturers of the equipment. Specific information on use of semiautomatic chart readers for conversion of hydrologic data is limited; however, two sources[3] [4] are listed for in-service use only.

The California State Department of Water Resources has modified and adapted semiautomatic chart readers to convert hydrologic data, mainly of one specific type. The hydrologic data are converted to digital form on IBM punch cards. These cards can then be processed directly through their own computer. The Department's modifications of the chart reader are to facilitate changes from one type of hydrologic chart to another and to make better use of the single freely variable axis available on the semiautomatic machine. Their primary interest is in water-level records for large streams where predominatly long, constant-time intervals (12 or 24 hours) are adequate. The semiautomatic chart reader is well suited to conversion of this type of record.

The primary objective of the chart reader program at the Coweeta Hydrologic Laboratory, U.S. Forest Service, Franklin, N.C., is to convert runoff records from Friez FW-1 water-level recorder charts to digital form for future computer processing. The hydrologists at this Laboratory make use of separate time-overlay lines and stage-overlay lines, and two channels of readout. The operator positions the time-overlay line to intersect the vertical (or curved) reference line and the chart trace, and then pushes the readout button. The system records the X-coordinate (time) while simultaneously switching to the second channel. The operator then moves his overlay (without moving the reference line) until the stage-overlay line intersects both the vertical reference line and the chart trace at the same point. When he pushes the readout button the second time, the system records the Y-coordinate (stage) and all remaining fixed information, and then returns to the first channel. The operator then moves the vertical reference to the next chosen point on the chart trace and repeats the entire operation. For long periods of base flow, the operator reverts to constant time intervals of 12 or 24 hours. The method is suited to recordings of long periods of relatively constant flow interspersed with periods of rapid fluctuation in stage. This procedure places the operator under less pressure than a fixed time-reading procedure would; however, this benefit may be offset by the added possibility of error from positioning and manipulating a second overlay trace.

Several features that should be considered in selecting semiautomatic chart readers are listed below:

1. The width and length of the viewing screen should be adequate to accommodate all types of hydrologic charts. General specifications should call for the effective screen width to

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[2] The mention of commercially manufactured equipment does not imply endorsement by the U.S. Department of Agriculture over similar equipment not mentioned.

[3] California State Department of Water Resources. Machine Systems for Stage-Discharge Relation Records. [n. d.]

[4] Hibbert, Alden R. Processing Streamflow Records for Machine Computation. 12 pp. June 1961. [Processed.]

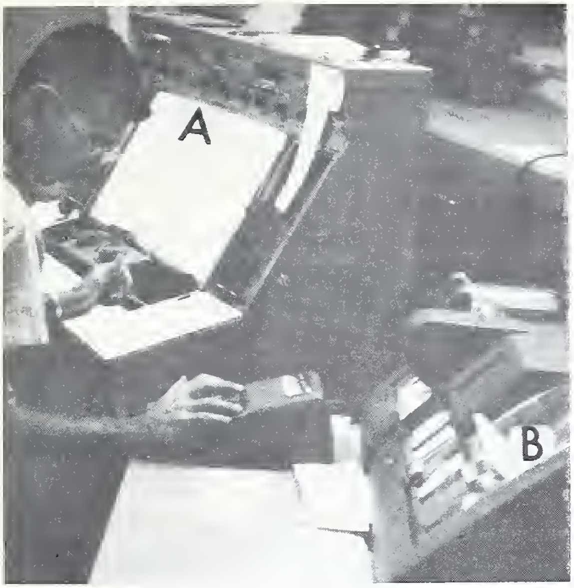

Figure 1.--SEMIAUTOMATIC CHART READER (with punch card attachment): (A) One-unit semiautomatic chart reader; and (B) IBM-26 punch card machine.

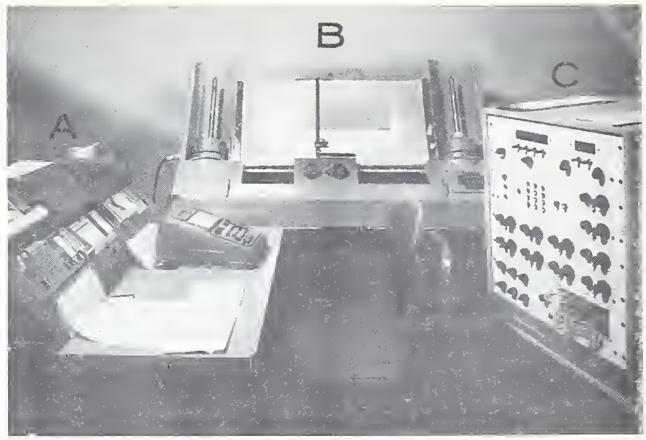

Figure 2.--AUTOMATIC CHART READER (with punch card attachment): (A) IBM-26 punch card machine; (B) automatic chart reader; and (C) decimal converter.

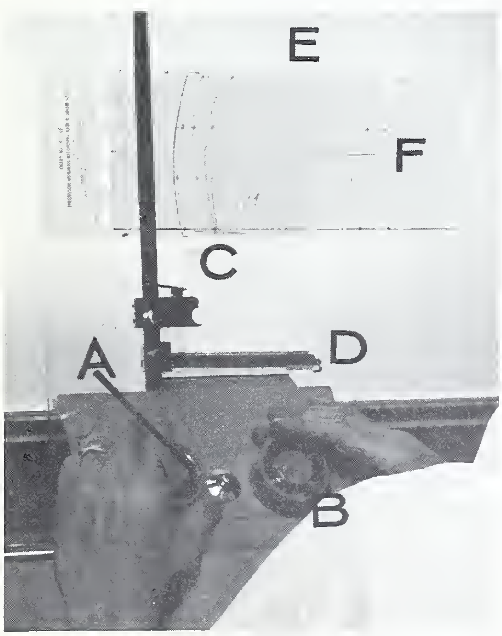

Figure 3.--AUTOMATIC CHART READER (close-up of screen and movable bridge); (A) Controls movable bridge (X-direction); (B) controls independent overlay trace; (C) curvilinear reference line; (D) overlay clamp; (E) overlay (depth of precipitation); and (F) recording rain gage chart.

exceed 12 inches, and length to exceed 16 inches. Since there is a "dead" area on most chart readers at each edge of the viewer, the overall screen length should be at least 24 inches.

2. The system should measure time increments directly in actual time units rather than linear units, which must be converted by the computer. This facilitates time checks. Most computer programs now utilize military time, which is an ideal unit for this system.

3. The system should be capable of transmitting information directly to a card punch and also to an electric typewriter.

4. It must be able to handle curvilinear charts and trace automatic reversals for folded vertical scales. One or both of these features occur on many hydrologic charts.

5. A manually directed 4-digit time-line counter is needed to record the movement of the carriage in the X-direction. In some programs, such as the one in use at Coweeta Hydrologic Laboratory, the time line counter can be ignored.

6. The unit should provide several separate channels for readout of multipen recorder charts, with an indicator to identify the channel in use.

7. A bank of selector switches should be provided to introduce fixed data such as watershed and measuring station designation, date, and codes. At least six fixed data switches should be supplied.

8. At present, most systems are limited to 3 digits (999 units) for the freely variable axis. The vertical scale can run from 0 to 999, 0 to 99.9, or 0 to 9.99. This limits the versatility of most semiautomatic systems, since four significant figures are needed for many hydrologic programs.

9. Machine accuracy as stated by the manufacturer has little significance. Overlay and reference line accuracy far outweight other considerations of accuracy. The minimum accuracy of one full-scale traverse should be within $\pm$ 0.1 percent.

10. Most chart readers are equipped with motorized spools at each end of the viewer, which supposedly facilitate conversion of data from continuous (strip) charts. These spools have proved to be unsatisfactory. It is simpler and more efficient for the operator to move strip charts manually across the viewer, since the operator must always realine the chart after it has been moved.

AUTOMATIC CHART READERS

Automatic chart readers vary widely in design, performance, and cost. In this publication only the less expensive automatic systems that are entirely suitable for analog to digital conversion of hydrologic data are discussed. Figures 2 and 3 show one of these less expensive systems. Several chart readers are available that give far greater accuracy and operate at greater speeds than those discussed here. The cost of these more refined machines is generally prohibitive if the system is to be used only to process hydrologic data and if it will be in operation only during the normal 40-hour work week.

In the automatic chart reader, both the X- and Y-axes are freely variable. That is, movement along a trace will be automatically recorded for any point in both the X- and Y-directions. The operator is no longer responsible for predetermining the movement along the X-axis or for switching between two overlay traces to complete each reading. All information pertaining to one point is recorded when the readout button is pushed. This system, as was indicated earlier, is more valuable when the intervals in both the X- and Y-directions vary widely and unevenly. Records of convective precipitation and runoff records with abruptly changing stages are examples of such traces that need to be read at natural "break points" for accurate determination of time-rate relationships.

The automatic chart reader has a series of Y-axis channels. These added Y-axis channels greatly facilitate the handling of multiple traces, particularly when the traces are based on different scales. Each Y-axis can be set with a different origin and scale. These channels can be switched on or off as desired, so that the appropriate scale for one trace or one chart can be retained by the machine for later use while another type trace is being scanned. The origin and scale of the axis can remain fixed as long as there are sufficient channels to hold all programs consecutively used, which are based on the same time scale. Hydrologic records for the Agricultural Research Service's Walnut Gulch Experimental Watershed, Ariz., consist of three types

of rain gage charts (6-inch single traverse, 3-inch double traverse, and 1 1/2-inch triple traverse) and three types of water-level records (Leupold and Stevens A-35, Friez FD-4, and Friez FW-1). The range of the hydrologic variable, i.e., inches of precipitation or feet of stage, differs for single traverse on each of these charts, so the scale on each chart is set on separate channels on the automatic chart reader used for these records. Only the scale for the X-axis must be changed from program to program, and that only for the latter three programs.

Another feature of the automatic chart reader is an error control. If for some reason the machine attempts to record a value other than the correct position relative to either axis, the machine stops and an error light flashes. If the overlay is moved before the readout is completed, the machine does not stop but the light flashes on. This feature, while appearing to be somewhat theatrical, has proved to be exceedingly helpful in minimizing the errors in machine operation.

The relative features of semiautomatic and automatic systems will be more thoroughly developed in the following discussion of their use with specific hydrologic charts.

CONVERSION OF 6-HOUR, 12-HOUR, AND 24-HOUR PRECIPITATION CHARTS

Both semiautomatic and automatic chart readers have been used to convert data from precipitation charts to digital form. Semiautomatic systems are especially well adapted to processing precipitation records from frontal-type storms where intervals of 15, 30, or 60 minutes can be used. Records from convective thunderstorms, where shorter time intervals are desirable, can also be processed with the semiautomatic chart reader, but with considerably more difficulty. The operator can, with either a double trace system, as developed by the Coweeta Hydrologic Laboratory, or by "eyeballing it in," record traces at 5-minute intervals on 24-hour charts with reasonable accuracy. For shorter intervals, which are often desired in studies of convective storms, offset scales can be drawn or taped at the top of the viewer. Precipitation can be accurately recorded at 2-minute intervals for 24-hour charts when the vertical reference line is moved from one scale to the next (usually four 8-minute interval scales are used). The same offset scale can be used to read intervals of 1 minute on a 12-hour chart and one-half minute on a 6-hour chart. A variation of this procedure is to draft three vertical lines parallel and offset by 2-minute increments from the vertical reference line and to use each line successively as the reference. Although both double trace and offset scale methods are reasonably accurate, the added pressure on the operator results in numerous operator errors.

If a large part of the precipitation record consists of convective rains, the automatic chart reader, although approximately twice as expensive as the semiautomatic system, may be justified. The Southwest Watershed Research Center is responsible for processing precipitation records from approximately 150 recording rain gages in Arizona and New Mexico. Records have been processed on both types of chart readers, and it was determined that the purchase of the more expensive automatic chart reader was justified on the basis of processing these precipitation records alone.

The question most often asked in regard to chart readers concerns operation time for one or a given number of charts. The time spent processing precipitation records from a given number of gages for a given period varies tremendously. The precipitation record for a recording rain gage for an average year on the Walnut Gulch Experimental Watershed at Tombstone, Ariz., consists of 30 to 40 charts. The number of gage-years of record processed per day on a semiautomatic chart reader has ranged from two for a relatively wet year to four for a relatively dry

year. In general, charts with records of small summer or frontal rains, where intensities and total amounts are low, can be processed only slightly more rapidly than those showing large convective summer rains.

With the automatic chart reader, selecting the "break points" and procuring the output cards are the least time-consuming parts of the operation; most of the time is spent changing and adjusting the charts on the reader and recording the fixed information (watershed number, date, and beginning time). The precipitation records to be processed vary so widely in both clarity and chart type that general values of machine time per chart are valueless, except to point out relative advantages over "manual" chart reading. Anyone who has gone through the tedious, time-consuming, eye-straining process of reading and manually tabulating data from precipitation charts can fully appreciate the qualitative value of chart readers.

The added efficiency of an automatic over a semiautomatic chart reader is somewhat offset by a machine source of error in rainfall intensity for short-time intervals. The automatic chart reader records time to the nearest unit value. For example, two points that read out as separated by a 2-minute time interval actually can be from 1.51 to 2.49 minutes apart. Although such error is randomly distributed, the maximum error possible is too large to ignore. An offset scale, such as the one used on the semiautomatic chart reader, can be used effectively to reduce the possible magnitude of the error. However, use of the offset scale decreases the speed of operation and increases the strain on the operator. The minimum acceptable time interval, as stated earlier, should be 2 minutes for 24-hour charts, 1 minute for 12-hour charts, and 1/2 minute for 6-hour charts. Minimum time intervals for precipitation charts with time scales other than 6, 12, or 24 hours should be calculated from the same ratio as applied above.

At the Southwest Watershed Research Center, several precipitation records were processed by hand and by machine. Maximum depths and intensities computed by four persons, independently, for an intense storm on the Alamogordo Creek Watershed, New Mex., are given in tables 1 and 2. Two persons used the automatic chart reader; two did not. The machine values were derived without use of an offset scale. Much more time was spent by each of the men who did not use the chart reader.

TABLE 1.--Readings of accumulated depths and duration of precipitation at Alamogordo Creek, N. Mex., as processed by hand and by machine

Operator	Accumulated depth of rainfall for an interval of--					
	2 minutes	5 minutes	10 minutes	15 minutes	20 minutes	30 minutes
	Inch	Inches	Inches	Inches	Inches	Inches
1st man-----	0.75	1.16	2.25	3.05	----	----
2d man------	.50	1.25	2.33	3.06	3.30	3.35
1st machine-	.66	1.51	2.39	3.09	3.27	3.38
2d machine--	.77	1.51	2.20	3.06	----	----

TABLE 2.--Readings of maximum intensities for selected periods of precipitation at Alamogordo Creek, N. Mex., as processed by hand and by machine

Operator	Maximum intensities recorded for an interval of-					
	2 minutes	5 minutes	10 minutes	15 minutes	20 minutes	30 minutes
	In./hr.	In./hr.	In./hr.	In./hr.	In./hr.	In./hr.
1st man-----	22.50	13.92	13.50	12.20	----	----
2d man------	15.00	15.00	13.98	12.24	9.90	6.70
1st machine-	19.80	18.12	14.34	12.36	9.81	6.76
2d machine--	23.10	18.12	13.20	12.24	----	----

The four sets of computations varied considerably, but the two sets of machine values, except for the maximum 2-minute interval, are nearly identical. Use of an offset scale would lessen the difference between the short interval values. This test, along with others, has indicated that the automatic chart readers can be used to process precipitation records from convective rains much more rapidly and somewhat more accurately than manual procedures.

When a line is traced by the pen on a curvilinear chart while the chart drum is stationary on the recording instrument and a difference is indicated in time between the trace at the top and bottom of the chart, the trace is said to be "skewed." Skew in hydrologic charts can be traced to the mechanical misadjustment of the recorder or to the placement of the chart on the recorder, and should be corrected in the field. If charts with known skew must be processed, a special overlay can be drawn to correct the error. If a large number of charts have varying degrees of skew, a family of overlays can be developed. There is no easy way to correct for skew on either the semiautomatic or automatic chart reader. However, corrections can be made more precisely by using the chart reader than by manual techniques.

The scale on the automatic chart reader can be adjusted quickly to correct for a depth-recording error on a precipitation chart. For example, if the pen records 1.50 inches and the precipitation volume in the recorder bucket, as measured by a standard tube, is 1.75 inches, a correction is necessary. The overlay line is moved to intersect the reference line at 1.50 inches, and the scale is adjusted to read 1.75 at this point. Thus, the output will change from 0 to 1.75 while the overlay is moved from 0 to 1.50 on the chart. It is assumed that the error is a linear function of the depth, and that the same percentage of error is present at any point on the trace.

Most problems discussed for processing precipitation records apply to all hydrologic charts.

CONVERSION OF FRIEZ FW-1 WATER-LEVEL RECORDS

8-Day Charts

Semiautomatic chart readers are well adapted to processing runoff records from 8-day charts. Most 8-day charts record runoff from long periods of relatively steady flow. Readings are generally recorded at noon and or at midnight. A second overlay trace, as described earlier, can be used to tabulate changing stages for shorter time intervals as necessitated by storm periods. Since most of the operating time is spent changing and alining charts, the automatic chart reader has no advantage here. The minimum time interval discernible on the 8-day charts is 15 minutes.

6-Hour Charts

Several FW-1 recorders operating at 6 hours per traverse are in use by the Southwest Watershed Research Center. Sharp hydrographs result from intense convective rains of small areal extent. The automatic chart reader is ideal for processing these records. However, the relatively small number of these charts to be processed does not alone justify the purchase of the automatic machine. The semiautomatic chart reader with an offset time scale, as described above for precipitation charts, can be used to accurately convert the hydrographs from these extreme events to digital form.

CONVERSION OF FRIEZ FD-4 WATER-LEVEL RECORDS

Various time scales are used on FD-4 water-level records. The same arguments that apply to FW-1 records apply here, although the rectilinear coordinates on the FD-4 charts are easier to handle and involve less chance for error. Time intervals as short as 1/2 minute can be read accurately from an 8-hour-per-traverse chart. On a watershed such as Walnut Gulch, the relatively small number of FD-4 records does not, in itself, justify the purchase of the automatic chart reader. Again, if sufficient records are to be processed, the automatic system is desirable.

CONVERSION OF LEUPOLD AND STEVENS A-35 CONTINUOUS WATER-LEVEL RECORDS

Scale--4.8 Inches Per Day

Each time division on this chart scale equals 30 minutes. Usually, compact time intervals of this magnitude are used to record changing stage on large rivers for which stage changes occur smoothly and relatively slowly over periods of days, for even the largest floods. The semiautomatic chart reader is best adapted for records of this kind.

Scale--9.6 Inches Per Day

This is probably the most common time scale used on A-35 continuous water-level recorders. Each time division on the chart equals 15 minutes. The scale is compact enough to

economically record long periods of low flow but open enough to give a comparatively good record for rapid changes in water level. If the recording stations are located where channel conditions are stable or where permanent structures control the flow, the semiautomatic chart reader is adequate. However, for stations with shifting controls, the use of automatic chart readers is desirable. For example, A-35 water-level recorders located on the Agricultural Research Service's Pigeon Roost Experimental Watershed in Mississippi record runoff in shifting sand-bottom channels. Discharge must be computed from water-surface elevations corrected for both changes in the channel bottom and the flow regime. These corrections can be combined with the chart-reading operation; that is, one overlay can be used to record the two traces consecutively. As mentioned earlier, the automatic chart reader is best adapted to records with rapidly varying traces and multiple traces, and since both conditions exist on the Pigeon Roost Watershed, use of the automatic chart reader is justified there on the basis of the A-35 records alone.

Scale--28.8 Inches Per Day

For recording the high velocity, sharp-peaked, short-duration flows on the Walnut Gulch Watershed, the time scale is spread out so that each chart division represents 5 minutes. Points may be read at intervals as short as one-half minute, but normally 1 minute is the minimum. When intervals of one-half minute are necessary for this or any other chart, a special program must be developed. The semiautomatic machine can record time from 0 to 9999 units or to 999.9 units, and the automatic system can record time from 0 to 999, or to 99.9. Therefore, reading 1/2-minute intervals on the automatic system shortens the time range to just under 100 minutes, which is commonly less than the duration of the flow event. This problem can be solved by using one Y-axis for the time from 0 to 99.9 minutes for rapidly varying stages and then switching to a second channel that is set from 0 to 999 for portions of the record not requiring close-interval readings. This more involved method will, however, lead to more errors, so readings to one-half minute must be absolutely necessary before such a program is used. It may be that a "second look" will convince the hydrologist that readings to one-half minute would indicate a greater accuracy than the records warrant. If enough such open scale records are involved, the automatic chart reader is more desirable than the semiautomatic chart reader.

CONVERSION OF OTHER HYDROLOGIC CHARTS

Both semiautomatic and automatic systems can be used to process data from every type of hydrologic chart so far encountered. Quite often, a few charts of one specific type can be more easily processed by hand than by machine. The usual test is quantity. The more charts to be processed, the more attractive becomes the chart reader. Decision between semiautomatic and automatic chart readers should be based on the constancy of the record trace, and whether there is more than one trace on a chart. In general, the more complex charts are best processed with the automatic system.

SUMMARY AND CONCLUSIONS

Chart readers can materially reduce the time required for processing analog recorder charts and increase accuracy in tabulating the data. The automatic chart reader may be desirable for processing certain types of charts, but there may be too few charts of these types to warrant

purchase of this more expensive system. The automatic chart reader can be justified either because of a large quantity of one type of chart to be processed, or because of smaller quantities of several types of charts to be processed. The automatic system is justified, for example, at the Agricultural Research Service's Southwest Watershed Research Center for both reasons. As shown previously, data from convective storms are recorded by 150 rain gages, and these records are best processed by the automatic system. Records from FW-1, FD-4, and A-35 recorders must also be processed. The quantity of charts to be processed each year for each of these is insufficient to warrant purchase of the automatic system, but the combined requirement for processing the three types of runoff records is sufficient to justify such a purchase.

Data converted by semiautomatic and automatic chart readers can be automatically transferred onto punch cards or tape for storage and quick efficient data reduction and analysis through automatic digital computers.

It appears that for many watershed research projects, the number or variety of hydrologic records or the combination of these factors would warrant the purchase of an automatic chart reader. Before such purchase is made, however, the merits of both the automatic and semiautomatic systems should be carefully weighed. If possible, sample charts typical of the particular research program should be processed on both automatic and semiautomatic systems.

Compared with a system employing direct digital recording gages, equipment will generally be less expensive for converting data from analog records, and the results better suited to many research purposes. In many instances, use of digital type field recorders would involve replacement of much existing equipment. Also, special office equipment is required to convert data from digital recorder tapes to computer cards or tapes. From the standpoint of visual evaluation of the records, analog recorders are preferred for the selection of data for particular studies, and for correction of records for irregularities in the measurements. Overall accuracy of results may well favor analog recording and conversion of the data to the digital form, using chart readers as discussed in this publication.